DESIGN OF A SINGLE-PHASE CASCADED H-BRIDGE MULTILEVEL INVERTER

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ABSTRACT. The significant disadvantages of two-level inverter include high harmonic distortion, limited output voltage waveform due to only two voltage levels and higher switching losses. This paper proposed a modelling approach for designing a single-phase cascaded H bridge multilevel inverter with a resistive load. The fundamental contribution of this project is the simplification of the suggested system: two equal DC sources, each equivalent to 1kVdc, a 50 Hz working frequency, and eight MOSFET switches. The pulse is created using the SPWM bipolar multicarrier approach, which compares the modulating signal with four phase-locked carrier signals. The appropriate modulating index, which reflects the relationship between the fundamental voltage and the input dc voltage, has been determined to generate an output voltage of 1kVrms. This can be accomplished using MATLAB/Simulink to build and simulate a single-phase cascaded H bridge multilevel inverter with a resistive load. Theoretical work has been done to verify the suggested system's correctness. For a better understanding, these values will be compared to simulation findings. The result shows that sinusoidal voltage values of 2000 Vpeak with a fundamental voltage of 1410 V were obtained in the form of a five-level staircase with the following values: 2000V, 1000V, 0V, -1000V, -2000V. However, because of the high-frequency PWM inverter, an LC filter was utilized to filter out the harmonics, resulting in sinusoidal output voltage and lower total harmonics.

KEYWORDS: inverter; h-bridge; cascaded; spwm

1 INTRODUCTION

Most power systems or electrical appliances have adopted the inverter into their respective applications widely in the past few decades. Basically, an inverter is defined as the direction of power flow from direct current (DC) to alternating current (AC) for a power electronic device. The other name for the inverter is the DC-AC converter. It takes an important role across various fields for example flexible AC transmission systems, high voltage DC power transmission, active filters as well as air conditioning (Gupta, Ranjan, Bhatnagar, Sahu, & Jain, 2015). Inverters can be categorized into several types such as square wave inverters, quasi-square wave inverters, and multilevel inverters. These are based on their output waveform nature. A connected power semiconductor cannot be done without directly switching high-voltage networks (Xiao et al., 2014). Thus, multilevel inverters are implemented and continuously developed in situations of high voltage and medium voltage. In order to perform the power conversion as well as produce multilevel voltage waveforms, power semiconductor switches are used that are able to achieve higher power from lower voltage DC levels (Gupta et al., 2015). In fact, the inverter is now being advanced to different topologies, from neural-point-clamped multilevel inverters to modular multilevel inverters (Babaei, Laali, & Bayat, 2014; Barah, S.S and Behera S,2021). Among these configurations, the single-phase cascaded H-bridge multilevel inverters is one of the most commonly used and also known as the origin of "modern" multilevel inverters (Akagi, 2017). It is intended to reduce the total cost and the switching loss with improving the efficiency at the optimum level (Anan, Chakraborty & Mahmood, 2018). The switching losses are being highlighted with that minimize or even avoid the necessary output filters.

On the other hand, a switched output waveform is obtained while the gate signals are produced by a modulation technique from the adjusted components of power semiconductors (Leon, Kouro, Franquelo, Rodriguez, & Wu, 2016). Pulse width modulation is the fundamental technique of power electronics as well as an effective way to generate and control the desired output waveform. There are various techniques aiming to shape the output waveform as an ideal sinusoidal waveform. For example, sinusoidal pulse width modulation, modified pulse width modulation, space vector modulation and

specific harmonic elimination. Sinusoidal pulse width modulation is known as the carrier-based technique to get high quality waveforms, using higher device switching frequency. Note that the switching frequency is increased and reduces total harmonic distortion at the same time. However, it is a fact that it may cause to an increment of switching losses. Therefore, the main objective is to design and implement a single-phase cascaded H-Bridge Multilevel Inverter connected to a resistive load that produces a sinusoidal output voltage of 1kVrms using the appropriate parameters. After that, evaluate the simulation design with the theoretical side of the system by analyzing the waveform and harmonic spectrum for output voltage performance.

2 DESCRIPTION OF MULTILEVEL INVERTER COMPONENTS

2.1 Multilevel Inverter

The process of building a single-phase multilevel inverter began with defining the circuit and determining the inverters' specifications and parameters. By delivering a gate pulse to the two complete bridges, a single-phase 5-level cascaded H bridge multilevel inverter will create voltage levels of +Vdc, +2Vdc, 0, -Vdc, and -2Vdc. The multilayer inverter's switching states are depicted in Table 1.

Table 1: Switch States For 5 Level Cascade H Bridge Inverter

	0	Vdc	2Vdc	Vdc	0	-Vdc	-2Vdc	-Vdc
S1	0	1	1	1	0	0	0	0
S2	1	1	1	1	1	0	0	0
S3	0	0	0	0	0	1	1	1
S4	1	0	0	0	1	1	1	1
S5	0	0	1	0	0	0	0	0
S6	1	1	1	1	1	1	0	1
S7	0	0	0	0	0	0	1	0
S8	1	1	0	1	1	1	1	1

Table 2 shows the specifications and parameters of the single-phase 5 levels cascade H bridge that was discussed in this study.

Table 2: Specification and Parameter for 5-Level Cascade H Bridge

Parameter	Value
Output Level Inverter	5
Total Number of Switch	8
Full H-Bridge DC Source	1000 Vdc
Fundamental Frequency	50 Hz
Load	100Ω

2.2 Sinusoidal Power Modulation Method (SPWM) Design

The gate pulses for the eight MOSFET switches in this project are generated utilising Bipolar Multicarrier Sinusoidal Pulse Width Modulation (SPWM) techniques, in which one modulating signal is combined with four carrier signals. The devices in one leg are turned on or off in this system when the modulation signal, Vr, is compared to a high-frequency triangle wave, Vc. By comparing the modulation signal with the other high-frequency triangle wave, the gadget in the opposite leg is turned on or off. In the phase disposition modulation approach, on the other hand, all of the triangular carriers are in phase and are stacked one on top of the other, as seen in Figure 1.

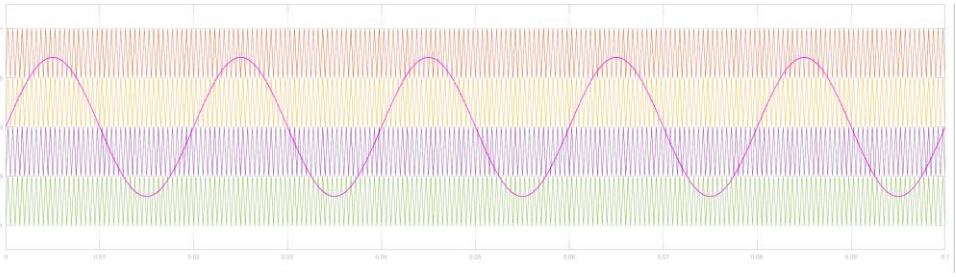

Figure 1: SPWM modulation and carrier signal.

The pulses for the multilevel inverter switches are obtained by comparing these configured triangular carriers to reference waves. This technique is widely acknowledged as producing the least harmonic distortion in line-to-line voltage.

2.3 Total Harmonic Disorder (THD)

Since the objective of the inverter is to use a dc voltage source to supply a load requiring ac, it is useful to describe the quality of the ac output. Total Harmonics Distortion (THD) is a measure of the non-sinusoidal wave's quality (THD). Equation (1) is used to measure the non-sinusoidal wave's quality (THD).

$$\text{THD} = \frac{\sqrt{V^2 rms - V^2 1 rms}}{V^2 1 rms} \quad (1)$$

2.4 LC Filter Design

LC filter is a circuit of inductors and capacitors combination used to filter high-frequency noise. Table 3 shows the parameter of the LC filter for required 1k Vrms output voltage.

Table 3: Specification and Parameter for LC Filter

Parameter	Value
Input Voltage	2000 Vdc
Inductor	22.1 mH
Capacitor	28.78 ⌈F
Load	100Ω

3 DATA AND RESULT

Simulations were carried out based on the requirements and parameters listed in Tables 1 and 2. The single-phase 5 level cascade H-Bridge inverter with two identical DC voltage sources, 1k Vdc each, modulating the frequency of 50Hz and the carrier frequency of 2k Hz has been applied. The voltage output waveform is obtained in the shape of a staircase, as illustrated in Figure 2 simulation results. Waveform analysis shows that it produces peak voltage values of 2000V in the form of five-level voltages of 2000V, 1000V, 0V, -1000V, -2000V, which are identical to the theoretical concept.

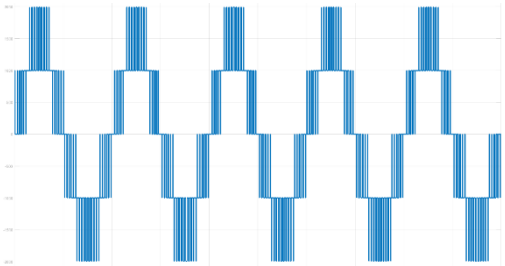

Figure 2: Voltage output waveform for 5 level Cascade H bridge inverter with SPWM technique

Table 4 represents the comparison of theoretical and simulation values produced for comparison purposes.

Table 4: Comparison Between Theoretical and Simulation Value

	Theoretical Value	Simulation Value
Peak Output Voltage	2000V	2000V
Fundamental Voltage	1414V	1405V
Total Harmonic Distortion	48.3%	42.40%

FFT analysis is used to examine the harmonic content of the output voltage of a 5-level cascade H-bridge multilevel inverter. Figure 3 depicts the output voltage's harmonic spectrum. The obtained fundamental voltage is 1405 V, which is lower than the theoretical value of 1414 V. Meanwhile, the multilayer inverter's output voltage has a total harmonic distortion of roughly 42.4%, which is lower than the theoretical SPWM approach. There are harmonics situated at higher frequencies, such as 2000 Hz and above, when applying the frequency modulation of 40.

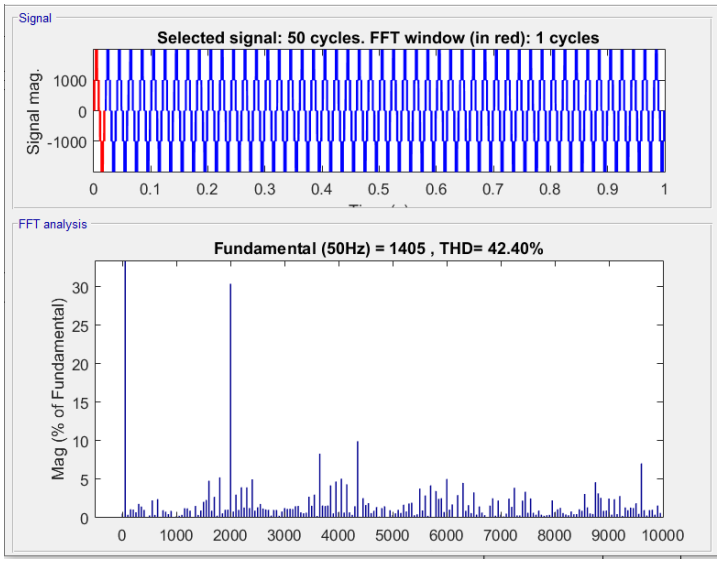

Figure 3: THD analysis of output voltage for bipolar SPWM 5 level CHMI

An LC filter is used to create a sinusoidal output voltage of 1000 V_{rms}, as shown in the APPENDIX, with an inductor value of 22.1 mH and a capacitor value of 28.78 µF. After filtering, the output voltage of a multilayer inverter is shown in Figure 4. As can be observed, a sinusoidal output voltage with a peak voltage of 1414 V was obtained.

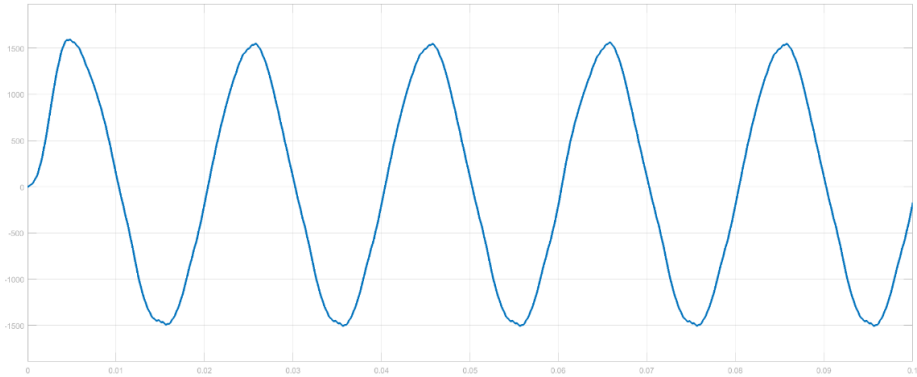

Figure 4 The output voltage waveform after filter

Harmonics at higher frequencies, such as 1000Hz and above, have been reduced using the LC filter. As a result, the multilevel inverter's total harmonics distortion has been decreased to 7.88%. The

fundamental frequency, on the other hand, falls to 1491 V. Figure 5 depicts the harmonic spectrum for sinusoidal output voltage for a 5-level cascade H-bridge inverter.

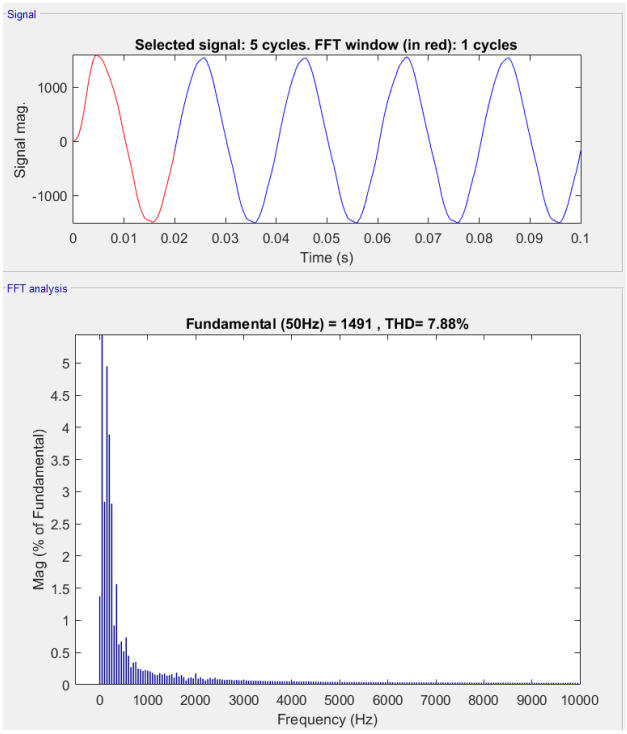

Figure 5 THD analysis of output voltage for bipolar SPWM 5 level CHMI after filter

4 DISCUSSION

This project is to analyze a single phase 5 level cascaded multilevel inverter. The multilevel inverter has two single-phases of full H-bridge inverter with 2 DC sources 1k Vdc each. The DC sources are connected in cascaded series, and the output voltage is the total of the two DC sources. This multilevel inverter can generate five different voltage levels, including +2Vdc, +Vdc, 0, -Vdc, and -2Vdc, as shown in Figure 5. With the help of a switching circuit, that is by using bipolar SPWM with multicarrier approach, which compares one modulating signal to four carrier signals and has the same frequency to reproduce a sinusoidal waveform by generating 4 pulses applied in the 8 actives switches of the inverter. Then, to produce a sinusoidal output voltage with lower harmonics, an LC filter is used. Table 5 shows the summary of finding for this project.

Table 5: Summary of Data Obtained

	Theoretical Value	Before Filter (Simulation Value)	After Filter (Simulation Value)
Output Voltage (Vpeak)	2000	2000	1592
Fundamental Voltage (V)	1414	1405	1491
THD voltage (%)	48.34	42.40	7.88

From the MATLAB/Simulink simulation, the output voltage generated using the SPWM approach and their FFT are shown in Figures 2 and 3. It can be observed that with applying Modulation Index, Ma=0.7071 resulting 2000 Vpeak with fundamental voltage 1405V in the form of 5 level output voltage. The outcome is consistent with the theory that when two full H-Bridge inverters are connected in cascaded will produce a sum of each full-bridge inverter, which is 2000V. However, by applying Modulation Ratio= 40, harmonics exist at the higher frequency beginning from 2000Hz with a total harmonic distortion of 42.40%. This harmonic distortion and losses in the fundamental voltage produced due to high switching frequency applied. The LC filter is introduced to eliminate harmonics at higher frequencies and reduce the total harmonic distortion. Figures 4 and 5 show that the harmonics are eliminated starting from 2000Hz and reduced to 7.88%, and output voltage 1491 V is obtained. From

observation, it can be concluded that nearly sinusoidal output and lower total harmonic distortion is produced.

5 CONCLUSION

In conclusion, a single-phase five-level cascaded H-bridge multilevel inverter has been successfully developed and simulated in MATLAB/Simulink. A 5-level output voltage in terms of 2000V, 1000V, 0v, -1000V, and 2000V has been obtained with a 1405V fundamental voltage. In addition, because of the high switching PWM approach, an LC low pass filter was built to reduce high-frequency harmonics, resulting in a sinusoidal output voltage. To summaries, all objectives were met because both theoretical and simulation aspects were used and coupled to obtain a study of the waveform and harmonic spectrum for the output voltage performance in the specified circuit.

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